

Attachment: Delivery Documentation for the Updated RXTE Onboard Star Catalog

This memorandum documents the analysis and quality assurance completed to produce the recently regenerated RXTE onboard star catalog. In addition, the report provides mission specific information such as the onboard catalog format and a detailed description of the onboard catalog quality flags. It also includes comparisons of the contents of the updated onboard catalog (OSC6) with that of the previous version of the onboard catalog (OSC5, completed in November 2000). (See Reference 2).

INTRODUCTION

The first post-launch revision of the original on-board star catalog for RXTE was based in large part (for astrometric, photometric, spectral type, and variability data, as well as approximately half of the sensor passband magnitudes) on the SKYMAP SKY2000 Version 3 Master Star Catalog (MC). The RXTE OSC5 contained 2,844 entries with predicted instrumental magnitudes in the range +0.843 to +6.669. (The nominal sensitivity range of the Ball CT-601 star trackers used by RXTE is +1.0 to +6.5.) Twelve entries were corrected to center-of-light (COL) positions to account for the interference of nearby, bright neighboring stars. The 2,844 star group in the RXTE OSC5 was the same as that selected for the pre-launch version of the RXTE OSC (OSC4D), and the catalog contained updated information in as many data fields as could be updated with the data available. Because variability information was known to be incomplete in the SKY2000 Version 3 MC, the variable star data in the RXTE OSC5 were incomplete and out of date, though they did represent an improvement over what had been available when the RXTE OSC4D was created.

The OSC5 had been created following an attitude anomaly experienced by RXTE in September 2000, which involved degradation of a measured OSC star position by a previously unaccounted for near-neighbor star. The near-neighbor star was variable and spectral type M8, and at times of maximum light would be have been separately detectable by the RXTE star trackers. The OSC5 replaced the affected guide star with another nearby star, but the RXTE OSC was not otherwise investigated for the presence of interfering near-neighbor stars.

The spacecraft experienced another attitude anomaly in November 2001, and the problem was again traced to interference with the tracking of an OSC star by a near-neighbor star. In this case, both the OSC star and the near-neighbor star were identified as variables. The "bad" OSC star was removed from the list of guide stars available to the onboard attitude control system, and efforts to create an updated OSC (OSC6) began. The

Mr. Sodano
Flight Dynamics Facility
Delivery of Updated Star Catalog for RXTE

- 2 -

March 15, 2002

primary goal of the OSC regeneration effort was to replace stars having interfering near-neighbors with stars bright enough to be tracked reliably, but which do not have interfering near-neighbor stars. Variability of OSC stars was considered to be a lesser concern, but variability of near-neighbor stars was noted where possible and such cases were analyzed further and handled individually. Potential replacement stars were themselves screened for possible interfering near-neighbor stars, brightness in the instrumental passband of the RXTE star trackers, variability, and spectral type (redder stars were avoided where possible).

A special star catalog was created to facilitate the examination of the OSC5 for guide stars with potentially interfering near-neighbors. It contained the SKY2000 Version 4 Master Catalog (itself recently created and containing completely replaced and updated variable star identifiers and variability data, see Reference 3) with added records for each star in the Tycho-1 star catalog (see Reference 4) not already included in the SKY2000 MC. The resulting augmented catalog contained 1,059,472 entries and was perhaps 99 percent complete to a Johnson *V* magnitude of 10. The records coming from the Tycho-1 catalog contain ICRS2000 positions (on the International Celestial Reference System, at epoch 2000) and Johnson *BV* photometry, enough data to compute angular separations between these stars and OSC stars and to compute instrumental magnitudes for these stars. This catalog was then searched for all stars within nine arcminutes of an RXTE OSC star, and all such stars were then processed through the SKYMAP MMSCAT program to obtain RXTE star tracker passband magnitudes for each star. Using the angular separations and tracker passband magnitude differences between the near-neighbor stars and the RXTE OSC stars, the near-neighbor criteria developed by P. Newman prior to launch ("Newman's" criteria.) (See Reference 5) were applied, and any RXTE OSC star with one or more near-neighbor stars failing these criteria was marked for replacement. The OSC star that was involved in the November 2001 attitude anomaly (SKYMAP 1070042, OSC 177) was among the stars identified for replacement in this fashion. RXTE OSC stars with faint star tracker passband magnitudes ($M > 6.43$) were treated in a similar fashion.

Each OSC star marked for replacement was then used as a starting point to search the SKYMAP RXTE ground star catalog for all ground catalog stars within five degrees of the OSC star which are bright enough to be detected by the RXTE star trackers. The resulting group of candidate replacement stars was reduced by removing all stars already in the OSC, and then by removing all stars failing the application of Newman's criteria as detailed above. The resulting group of candidate replacement stars for each associated

Mr. Sodano
Flight Dynamics Facility
Delivery of Updated Star Catalog for RXTE

- 3-

March 15, 2002

OSC star was then examined to select the "best" replacement star in the group. Criteria applied were: Tracker passband magnitude and proximity to the OSC star to be replaced, variability, spectral type, and near-neighbor status (stars with near-neighbors that passed Newman's criteria were avoided where possible in favor of stars with no near-neighbors within nine arcminutes). Proximity to the OSC star being replaced was a criterion because smaller separations would help to maintain the uniformity of coverage of the RXTE OSC over the Celestial Sphere. Stars for which no suitable candidate star was identified were retained if their violation of Newman's criteria was borderline, and otherwise were deleted.

Candidate stars were then assigned OSC identifiers (starting with 3003, in keeping with the two stars added to the OSC5 numbered 3001 and 3002) and added to the cross-reference file, which contained in each combined data record: OSC5, SKYMAP ground catalog, SKYMAP red magnitude subsystem report, and SKYMAP SKY2000 Version 4 MC data records. This combined data file was processed to draw relevant data from each source in each data record to produce the new RXTE onboard star catalog, OSC6.

CATALOGS PRODUCED

The OSC for RXTE has been regenerated using the SKY2000 Version 4 Master Catalog, and includes the replacement of 206 stars, the effective deletion of eight stars (four deleted, and four pairs each replaced by a single star), and the replacement of all variability data contained in the catalog. The stars were not entirely re-selected, but were screened using the original, pre-launch near-neighbor criteria for inclusion or exclusion. Hence, the updated OSC contains substantially the same stars as the original OSC, but with almost all stars failing the pre-launch near-neighbor criteria replaced. Stars with faint instrumental passband magnitudes, often seen as not trackable in mission data (e.g., OSC 2420), were also replaced. See Table 1 for a list of faint stars replaced in the RXTE OSC.

The resulting updated OSC contains 2,836 stars with predicted instrumental magnitudes between +0.843 and +6.427. Only one entry (19510175, OSC 572) is lacking *B-V* color and observed *V* magnitude data (a derived *V* magnitude is present). The following two pairs did not violate Newman's criteria and are represented by single entries with blended predicted instrumental magnitudes and positions corrected to COL (the first identifier is the one retained in the updated OSC): 2030134/2030178 (OSC 2428), and 5210128/5210140 (OSC 844). See Table 2 for COL pairs in RXTE OSC5 now replaced

Mr. Sodano
Flight Dynamics Facility
Delivery of Updated Star Catalog for RXTE

- 4-

March 15, 2002

with single stars. One star (8070217, OSC 103) that failed Newman's criteria was retained due to lack of suitable candidate stars. Three stars (17320122/2839, 20410234/41, and 21080132/40) were retained, as their violation of Newman's criteria was borderline in separation and/or magnitude difference.

The following RXTE OSC5 stars to be replaced were each near a single "good" candidate replacement star, and were replaced with single entries in OSC6: 2117/2041 (3162), 2265/2274 (3174), 694/684 (3074), and 78/114 (3013). The following RXTE OSC5 stars were deleted without replacement: 3, 4, 5, and 86. These stars, together with the OSC5 stars replaced by new stars in OSC6, are represented in Figure 1. The Galactic plane is somewhat visible in this figure, as the densest areas of the sky are those most likely to contain near-neighbor stars to the brighter OSC stars.

Mr. Sodano
Flight Dynamics Facility
Delivery of Updated Star Catalog for RXTE

- 5-

March 15, 2002

Table 1. Faint Stars and Replacements in the RXTE OSC5 and OSC6

Old OSC ID	Old OSC Mag	New OSC ID	New OSC Mag
186	6.440	3019	6.106
2154	6.471	3170	6.203
1339	6.473	3112	4.913
165	6.475	3020	6.191
2420	6.480	3181	6.187
2161	6.498	3166	5.397
239	6.526	3032	6.051
1204	6.545	3106	6.107
2117	6.547	3162	6.074
2616	6.554	3194	5.181
1941	6.555	3153	5.985
2136	6.645	3171	6.015
2101	6.669	3157	5.591

Mr. Sodano
Flight Dynamics Facility
Delivery of Updated Star Catalog for RXTE

- 6-

March 15, 2002

Table 2. OSC5 COL Pairs Replaced in OSC6

Old OSC ID	New OSC ID
247	3034
1933	3152
516	3056
1944	3151
850	3087
1907	3154
1124	3097
188	3024
648	3065
1120	3099

Mr. Sodano
 Flight Dynamics Facility
 Delivery of Updated Star Catalog for RXTE

- 7 -

March 15, 2002

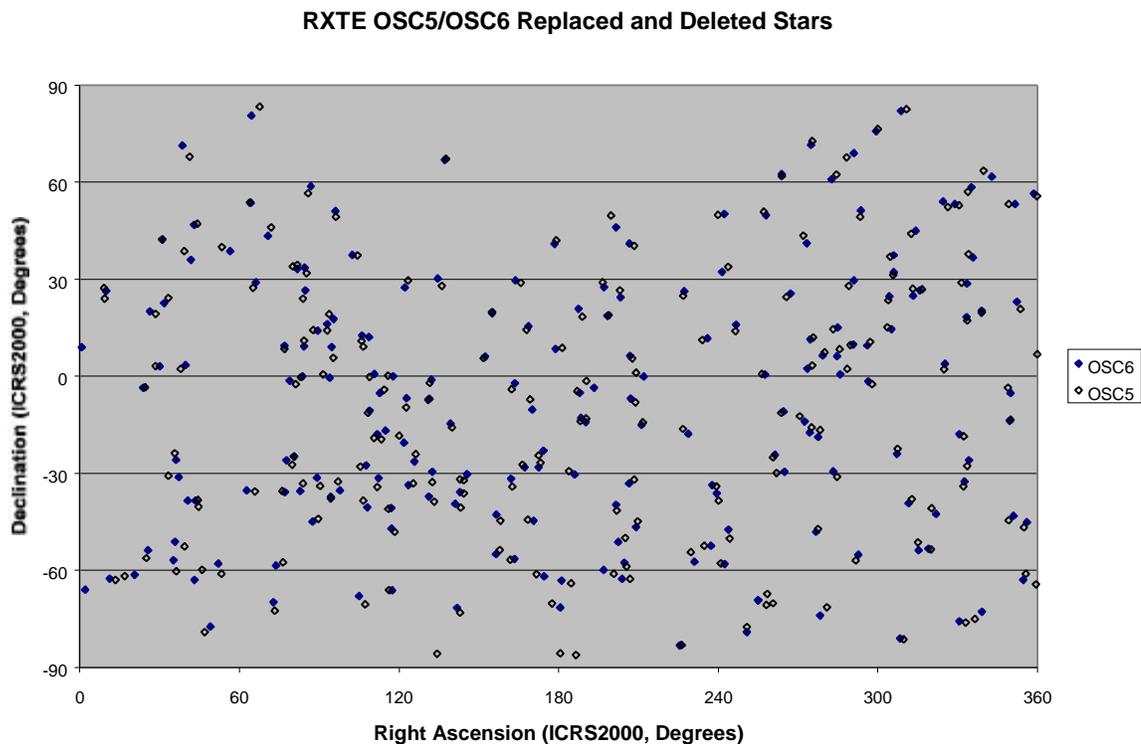


Figure 1. Replaced and Deleted OSC5 Stars with OSC6 Replacement Stars

RXTE OSC FORMAT AND QUALITY FLAG DEFINITIONS

The format of the updated OSC has not changed from that used in the past, although the content of each field may have changed somewhat. Table 3 describes the format of a data record in the updated OSC, while Tables 4 through 7 describe the mappings of OSC quality flags that were updated.

Mr. Sodano
 Flight Dynamics Facility
 Delivery of Updated Star Catalog for RXTE

- 8-

March 15, 2002

Table 3. Updated RXTE OSC Record Format

Name	Bytes*	Units	Description
SKYMAP ID	4-11		SKYMAP SKY2000 V4 Master Catalog identifier
OSC ID	13-16		On-board Star Catalog identifier
Right Ascension	19-26	deg	ICRS2000 Right Ascension (functionally the same as J2000)
Declination	29-36	deg	ICRS2000 Declination
R.A. Proper Motion	37-45	deg/yr	ICRS2000 Right Ascension proper motion
Dec. Proper Motion	46-54	deg/yr	ICRS2000 Declination proper motion
<i>B-V</i> Color	57-62	mag	Johnson <i>B</i> minus <i>V</i> color
<i>V</i> Observed	65-70	mag	Observed Johnson <i>V</i> magnitude
<i>V</i> Computed	73-78	mag	Computed Johnson <i>V</i> magnitude (if observed not available, else same)
Spectral Type	80-84		SKYMAP-coded spectral type
Variability Ampl.	86-93	mag	Amplitude of variability (in <i>V</i> passband, 0.0 if other or ampl. not known)
Nearest neighbor	95-101	deg	Angle from this star to nearest neighboring SKY2000 V4 MC star
Predicted Instr. Mag.	104-109	mag	Predicted CT-601 CCDST magnitude
Quality Flags	112-117		Quality flags 1: Data version (satisfied initial selection criteria) 2: Predicted CCDST magnitude 3: Variability amplitude 4: Proper motion magnitude 5: Near-neighbor proximity, magnitude difference 6: Method of computation for CCDST magnitude
Quality Flag	125		Overall quality flag 1: High (data version and near-neighbor quality flags both zero) 2: Low (else)

*All preceding or intervening bytes are blank.

Mr. Sodano
 Flight Dynamics Facility
 Delivery of Updated Star Catalog for RXTE

- 9-

March 15, 2002

The first quality flag field in the OSC is a six-byte field containing leading blanks. It is the initial selection criteria flag and has not been altered from what was contained in the pre-launch OSC. The second quality flag maps the brightness in the instrumental passband of an OSC star. Table 4 describes the mapping of values for this quality flag.

Table 4. Updated OSC Instrumental Magnitude Flag

Flag Value	Definition
0	$0.0 < \text{predicted instrumental magnitude} = 2.0$
1	$2.0 < \text{predicted instrumental magnitude} = 3.0$
2	$3.0 < \text{predicted instrumental magnitude} = 4.0$
3	$4.0 < \text{predicted instrumental magnitude} = 5.0$
4	$5.0 < \text{predicted instrumental magnitude} = 6.0$
5	$6.0 < \text{predicted instrumental magnitude}$

The third quality flag maps the variability amplitude of an OSC star. It is set to 0 for stars not known or suspected of variability (based on the SKY2000 V4 MC). It is also set to 0 for stars with amplitudes of variability in SKY2000 V4 in passbands other than the Johnson V passband or for known or suspected variable stars with unknown amplitudes of variability (including those coded "constant" in variable star catalogs). Stars with known variability amplitudes in the Johnson V passband are mapped as described in Table 5.

The fourth quality flag maps the RMS proper motion of an OSC star. The units are arcseconds per year, and the values are at ICRS2000. There are no OSC stars lacking proper motions. Table 6 describes the mapping of flag values to values of RMS proper motion.

Mr. Sodano
 Flight Dynamics Facility
 Delivery of Updated Star Catalog for RXTE

- 10-

March 15, 2002

The fifth quality flag is a near-neighbor flag that includes both proximity and brightness differences between a given OSC star and other nearby stars. This quality flag was not remapped in the update of the OSC due to lack of appropriate data. The sixth quality flag maps the computational source of the predicted CCDST magnitude in the updated OSC. Table 7 describes the mapping of this quality flag.

Table 5. Updated OSC Variability Amplitude Flag

Flag Value	Definition
0	Not a known or suspected variable, or variability amplitude not in Johnson <i>V</i> passband, or variability amplitude unknown
1	$0.0 < \text{variability amplitude} = 0.25$
2	$0.25 < \text{variability amplitude} = 0.5$
3	$0.5 < \text{variability amplitude} = 0.75$
4	$0.75 < \text{variability amplitude} = 1.0$
5	$1.0 < \text{variability amplitude} = 1.25$
6	$1.25 < \text{variability amplitude} = 1.5$
7	$1.5 < \text{variability amplitude} = 1.75$
8	$1.75 < \text{variability amplitude} = 2.0$
9	$2.0 < \text{variability amplitude}$

Mr. Sodano
 Flight Dynamics Facility
 Delivery of Updated Star Catalog for RXTE

- 11 -

March 15, 2002

Table 6. Updated OSC RMS Proper Motion Flag

Flag Value	Definition
0	$0.0 < \text{RMS proper motion} = 0.5$
1	$0.5 < \text{RMS proper motion} = 1.0$
2	$1.0 < \text{RMS proper motion} = 1.5$
3	$1.5 < \text{RMS proper motion} = 2.0$
4	$2.0 < \text{RMS proper motion} = 2.5$
5	$2.5 < \text{RMS proper motion} = 3.0$

Table 7. Updated OSC CCD Magnitude Computation Flag

Flag Value	Definition
0	Original OSC (observed V , $B-V$ color)
1	Original OSC (computed V , $B-V$ color)
2	Original OSC (observed V , spectral type)
3	Original OSC (computed V , spectral type)
4	Original OSC ($6500 < \text{coded spectral type} < 8000$)
5	Original OSC (no CCD magnitude prediction)
6	Updated OSC (RXTE or SWAS observed)
7	Updated OSC (MK spectral type, spectrophotometric scan)
8	Updated OSC (as 7, but no correction for reddening)

Mr. Sodano
Flight Dynamics Facility
Delivery of Updated Star Catalog for RXTE

- 12-

March 15, 2002

RECOMMENDATIONS FOR CATALOG USE

The updated OSC is an all-sky catalog (See Figure 2), just like the original RXTE OSC. A relatively small "hole" was introduced by the uncompensated deletion of three OSC stars around declination -85 degrees (See Figure 1). This is unlikely to cause problems during mission operations because the original OSC contained more stars than were actually required for mission use, and the spacecraft employs two star trackers operating simultaneously.

Variable stars with relatively small amplitudes of variability are included in the updated RXTE OSC. The identification and characterization of variable stars in the updated RXTE OSC is as good as the present state of knowledge permits because the SKY2000 V4 MC is complete in both variable star identifiers and in variability data. The present state of variable star data, however, is still insufficient to determine the variability amplitude of a particular star in the passband of the RXTE star trackers. Hence, the amplitude of variability in a standard passband (such as Johnson V) of a particular star cannot be used as the sole criterion for inclusion or exclusion of the star in the RXTE OSC. Replacement stars were selected to avoid known or suspected variable stars wherever possible, however.

Near-neighbor data in the RXTE OSC are as complete as available data permit. Stars not contained in the SKY2000 V4 MC are not taken into account, but will be fainter than ninth magnitude in the visual passband in most cases. All OSC stars, however, have been screened using the SKY2000 V4 plus Tycho-1 augmented catalog, which should contain almost all near-neighbor stars to a Johnson V magnitude of 10.0. Only four stars known to violate Newman's criteria have been retained, and of these three are borderline in their violation of the criteria.

Mr. Sodano
Flight Dynamics Facility
Delivery of Updated Star Catalog for RXTE

March 15, 2002

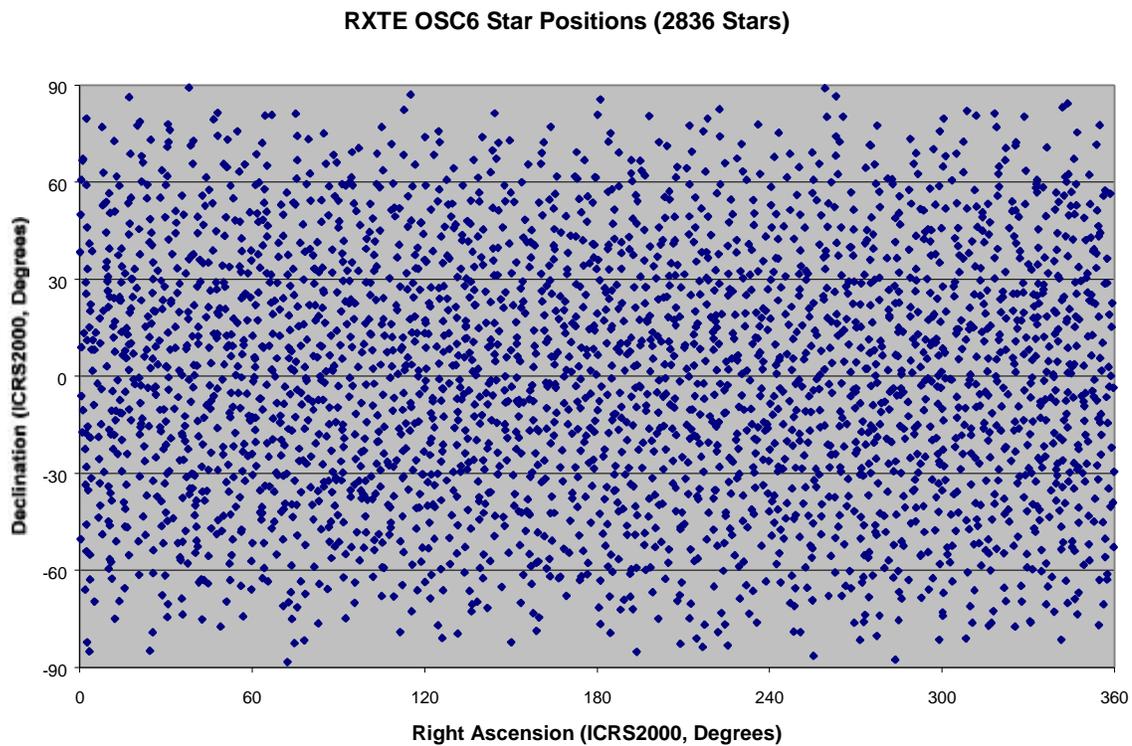


Figure 2. RXTE OSC6 Star Positions

Mr. Sodano
Flight Dynamics Facility
Delivery of Updated Star Catalog for RXTE

- 14-

March 15, 2002

REFERENCES

1. Sande, C. and N. Ottenstein. *SKYMAP Requirements, Functional, and Mathematical Specifications (Volume 3, Revision 3): SKYMAP SKY2000 Version 2 Master Catalog Format Specifications*, CSC-96-932-24, August 1999.
2. Sande, C. *Delivery of Updated Star Catalogs for RXTE*, memo to R. Sodano and N. Lenora, November 2000.
3. Sande, C. *SKYMAP SKY2000 Version 4 Master Catalog*, memo to T. Stengle, December 2001.
4. Høg, E. et al. *The Tycho Catalogue*, A&A 323, p. L57-L60.
5. Provided by M. Femiano, file "newcat.doc", May 1993.